The Square Kilometer Array: How will you use it for Communications and Navigation ?

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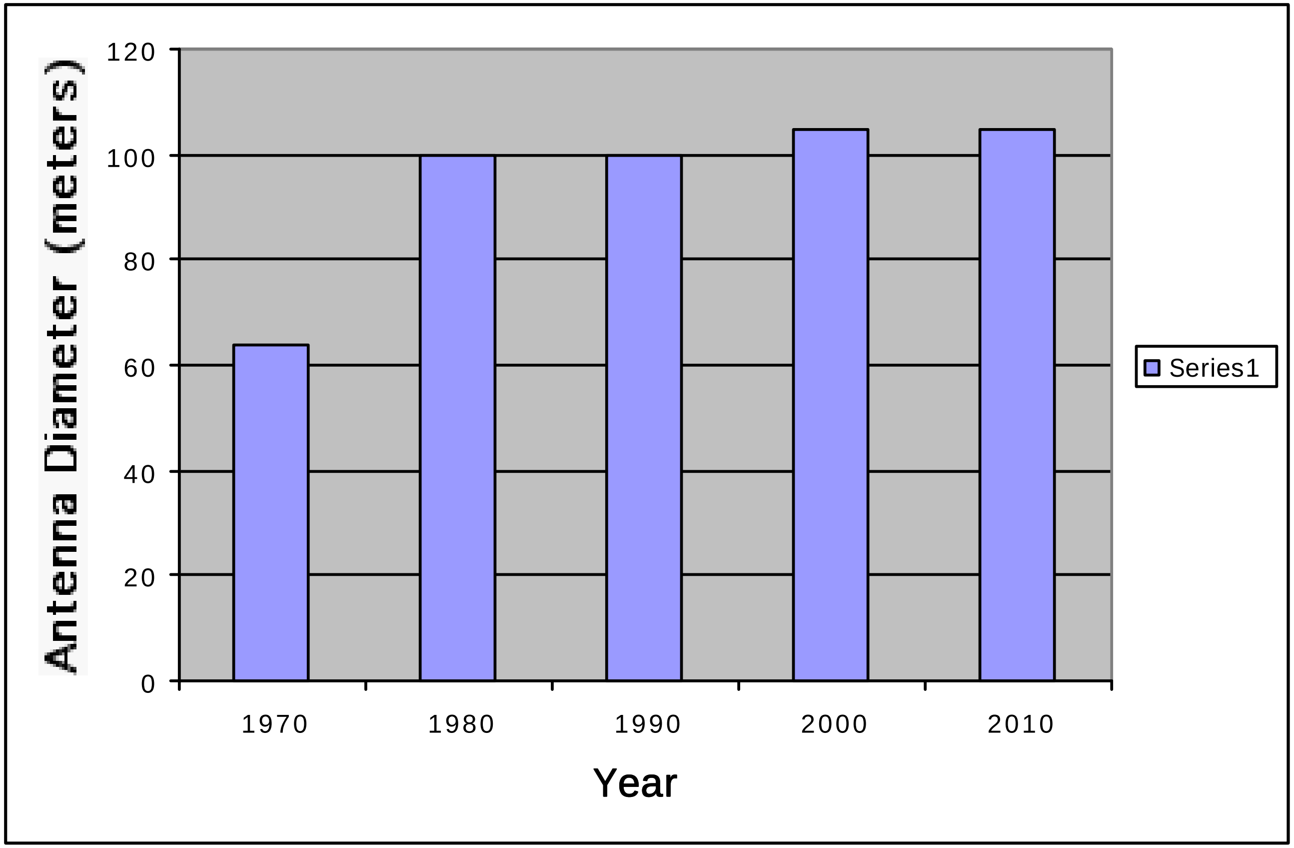
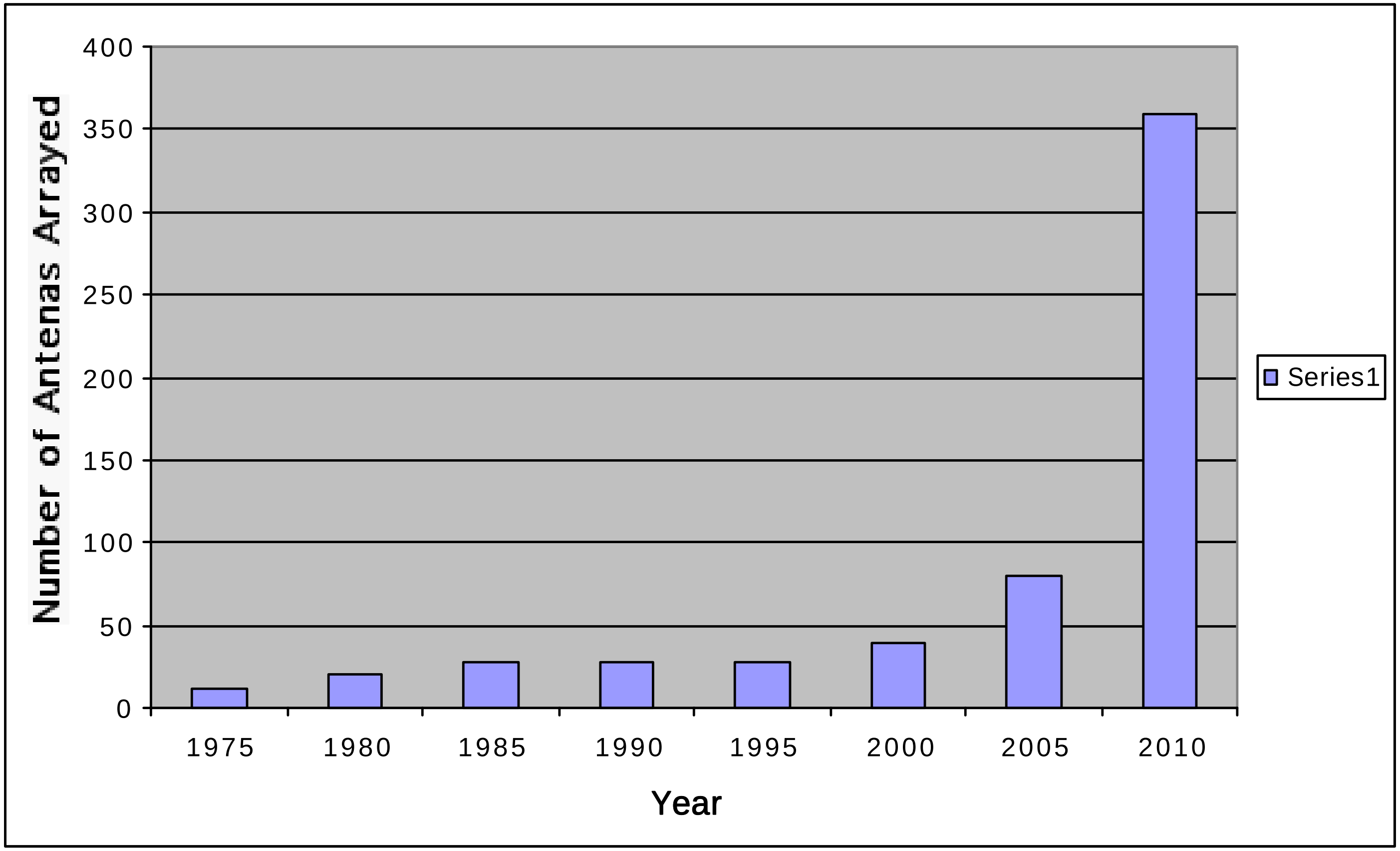
Presentation Purpose

- Inform the JPL community of the Radio Astronomy community's plans to build a radio telescope with a square kilometer of collecting area -- the Square Kilometer Array (SKA)
- Begin developing mission concepts and other applications for a major breakthrough in tracking station performance
- Develop the case for NASA/JPL participation in the planning, development, and implementation of the SKA

Largest Full-sky Antenna Size vs. Time



Number of Antennas Arrayed vs. Time



The Very Large Array

Arraying Antennas

Arraying requires adjusting the phase delay between antennas to “focus” the array

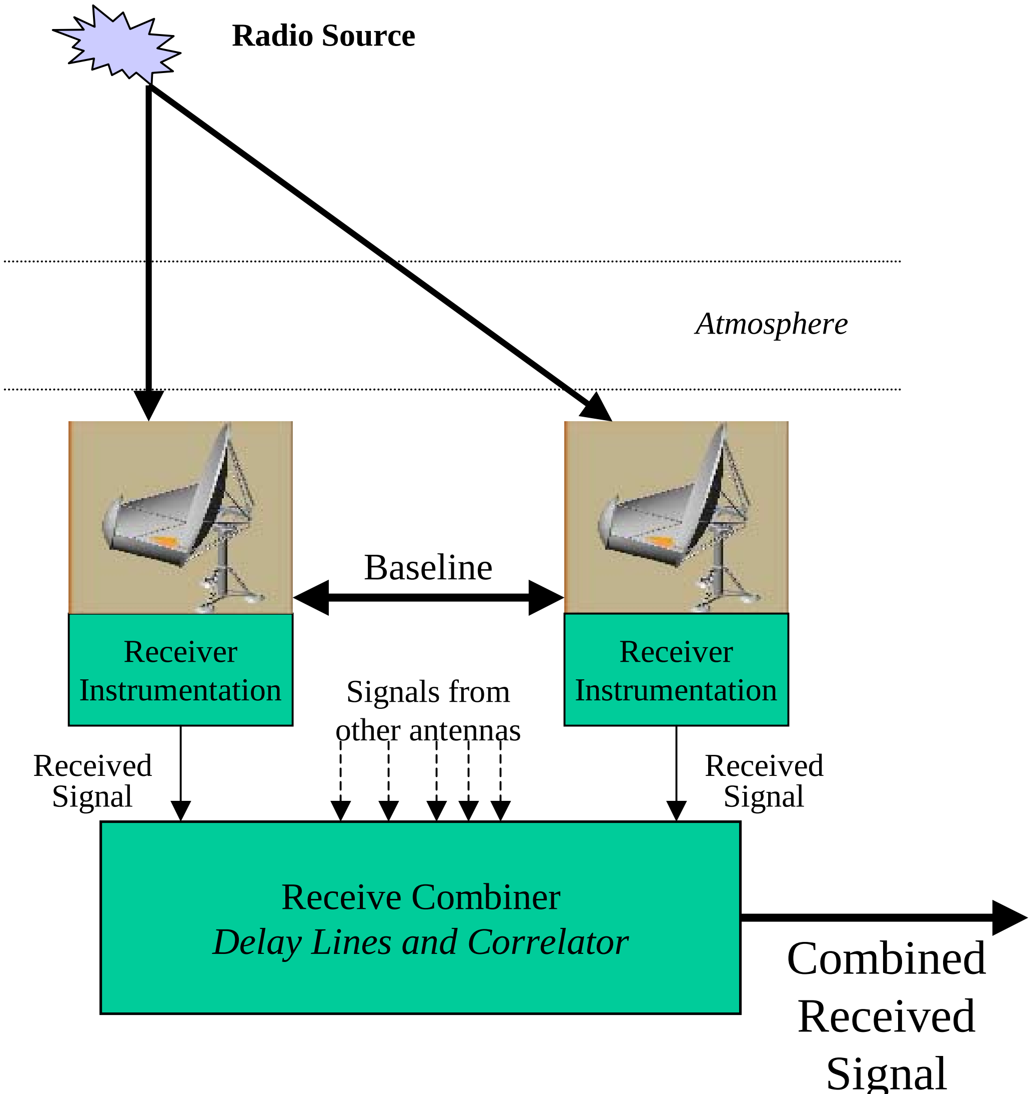
1. **Geometric Delay** is obtained from known antenna locations

2. **Propagation and Instrument Delay** are dynamic and different for each antenna

  – N(N-1)/2 baselines to correct N antenna phases

  – Observe radio source with known position and solve for optimum antenna phase delays

  – Array can then use even weak in-beam sources to stay “phased”



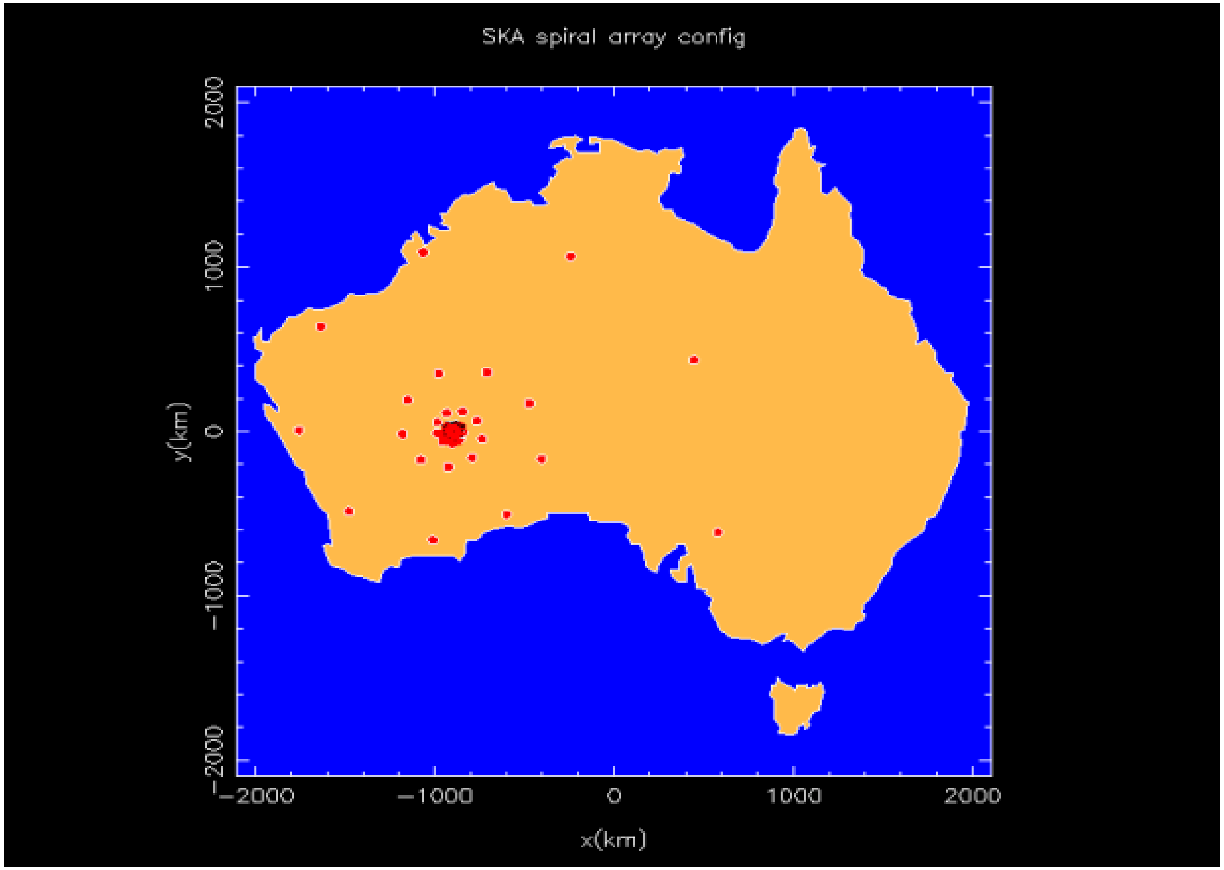
What is the Square Kilometer Array (SKA)?

A large aperture array of antennas with a collecting area of a square kilometer

- An array of antennas providing 100 times the sensitivity of today's best single aperture antennas
- Up to 100 simultaneous, independent fields of view (beams)
- High angular resolution
- 0.15 GHz to 22 GHz continuous frequency range
- Recommended by the Decadal Review
- Planned completion in 2015

The SKA
An Artist's Conception

The SKA
Example Array Geometry



SKA Applied to Radio Astronomy

- PROBE THE STRUCTURE OF THE UNIVERSE BEFORE THE DAWN OF GALAXIES (highly red shifted 21-cm radiation from the intergalactic media prior to re-ionization)
- CHART THE FORMATION AND EVOLUTION OF GALAXIES FROM THE EPOCH OF FORMATION (CO at $z > 3.5$; history of star formation at early epochs, unaffected by obscuration)
- PROBE DARK MATTER WITH GRAVITATIONAL LENSING (very wide field of view and extremely well defined point spread function)
- INVESTIGATE ACTIVE GALACTIC NUCLEI (huge increase in VLBI sensitivity; H_2O megamasers give distances and black hole masses)

SKA Applied to Radio Astronomy

Continued

- UNDERSTAND THE PHYSICAL MECHANISMS THAT GIVE RISE TO PLANETARY SYSTEMS (imaging of protostellar jets & proto-planetary disks; imaging stellar surfaces; planet detection via stellar astrometry)
- DETECT RADIO AFTERGLOWS FROM GAMMA-RAY BURSTS (rapid sub-arcsecond positions; expansion of fireball or jet)
- DETECT LONG-PERIOD GRAVITATIONAL WAVES (simultaneous timing of multiple pulsars; can detect ultra-massive black hole binaries anywhere in the Universe)

SKA vs. DSN 70m Stations

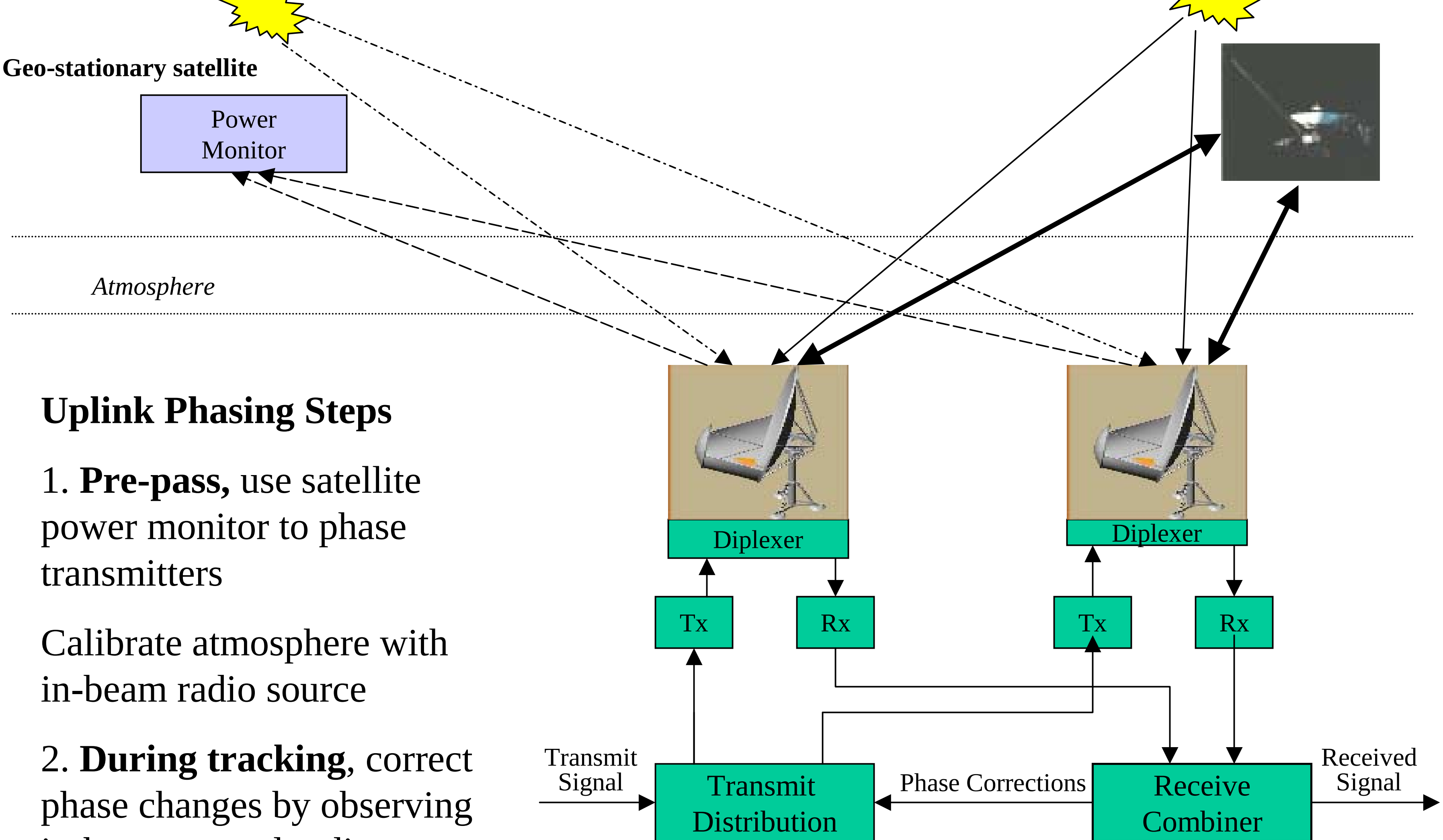
at X-band

	SKA	70m
G/T (dBi)	94+	74
delta f/f @10s	<1 E-13	<1 E-13
# beams	100	1
EIRP (comm)*	165+ dBm	145 dBm
EIRP (radar)**	181+ dBm	161 dBm

* 2W transmitters on 10,000 elements

** 50W transmitters on 10,000 elements

An Uplink Array Concept

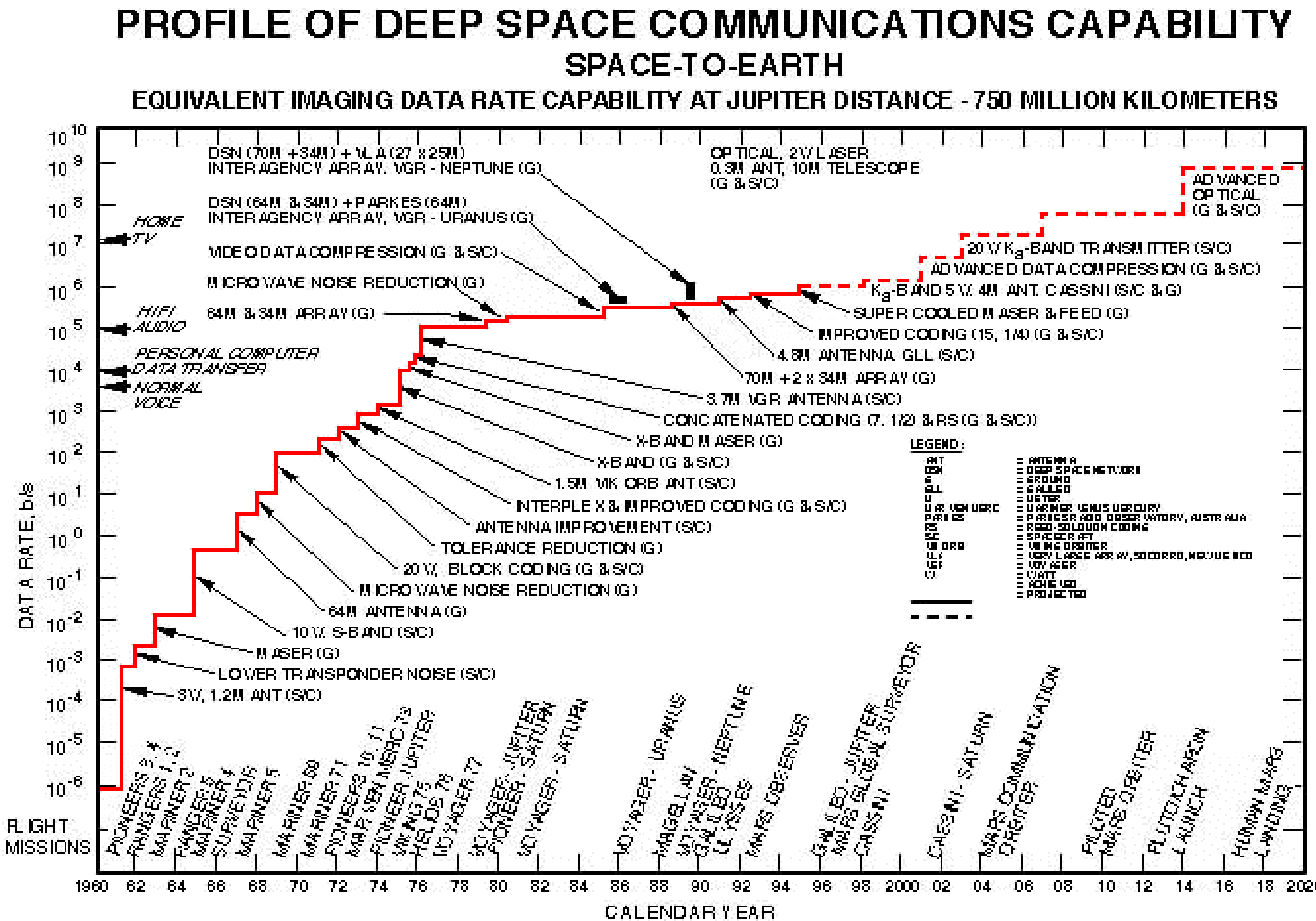


Uplink Phasing Steps

1. **Pre-pass,** use satellite power monitor to phase transmitters

Calibrate atmosphere with in-beam radio source

2. **During tracking**, correct phase changes by observing in-beam natural radio source


PROFILE OF DEEP SPACE COMMUNICATIONS CAPABILITY
SPACE-TO-EARTH
EQUIVALENT IMAGING DATA RATE CAPABILITY AT JUPITER DISTANCE - 750 MILLION KILOMETERS
DATA RATE, b/s
CALENDAR YEAR
FLIGHT MISSIONS
HOME TV
HIFI AUDIO
PERSONAL COMPUTER DATA TRANSFER
NORMAL VOICE
DSN (70M +34M) + VLA (27 x 25M) INTERAGENCY ARRAY, VGR - NEPTUNE (G)
DSN (64M & 34M) + PARKES (64M) INTERAGENCY ARRAY, VGR - URANUS (G)
VIDEO DATA COMPRESSION (G & S/C)
MICROWAVE NOISE REDUCTION (G)
64M & 34M ARRAY (G)
OPTICAL, 2W LASER 0.3M ANT, 10M TELESCOPE (G & S/C)
ADVANCED OPTICAL (G & S/C)
20 W Ka-BAND TRANSMITTER (S/C)
ADVANCED DATA COMPRESSION (G & S/C)
Ka-BAND 5 W, 4M ANT. CASSINI (S/C & G)
SUPERCOOLED MASER & FEED (G)
IMPROVED CODING (15, 1/4) (G & S/C)
4.8M ANTENNA, GLL (S/C)
70M + 2 x 34M ARRAY (G)
3.7M VGR ANTENNA (S/C)
CONCATENATED CODING (7, 1/2) & RS (G & S/C))
X-BAND MASER (G)
X-BAND (G & S/C)
1.5M VIK ORB ANT (S/C)
INTERPLEX & IMPROVED CODING (G & S/C)
ANTENNA IMPROVEMENT (S/C)
TOLERANCE REDUCTION (G)
20 W, BLOCK CODING (G & S/C)
MICROWAVE NOISE REDUCTION (G)
64M ANTENNA (G)
10 W, S-BAND (S/C)
MASER (G)
LOWER TRANSPONDER NOISE (S/C)
3W, 1.2M ANT (S/C)
LEGEND:
PIONEERS 3, 4
RANGERS 1, 2
MARINER 2
RANGER 5
MARINER 4
SURVEYOR
MARINER 5
MARINER 69
MARINER 71
PIONEERS 10, 11
MARINER VEN MERC 73
PIONEER JUPITER
VIKING 75
HELIOS 76
VOYAGER 77
VOYAGER - JUPITER
PIONEER - SATURN
VOYAGER - SATURN
VOYAGER - URANUS
MAGELLAN
VOYAGER - NEPTUNE
GALILEO
ULYSSES
MARS OBSERVER
GALILEO - JUPITER
MARS GLOBAL SURVEYOR
CASSINI
CASSINI - SATURN
MARS COMMUNICATION ORBITER
PILOTED MARS ORBITER
PLUTO/CHARON LAUNCH
HUMAN MARS LANDING

SKA Applied to
Deep Space Communications

- Use SKA to increase data rate by a factor of 100+
  - Enhanced science observations
    - Movies instead of images
    - More complete target coverage
      - MRO will only image 1 - 2% of Mars at the highest resolution
    - High resolution, multi-spectral imaging
      - Current instrument produce ~ 100 more data than link capacity
    - Enhanced SAR mapping
  - New science enabled
    - ?
  - New missions enabled
    - Hostile environments with limited spacecraft life
    - Multi-channel HDTV for Robotic Outposts, piloted missions
    - Interstellar probe missions

SKA Applied to
Deep Space Communications

Continued

- Use SKA to reduce spacecraft mass, cost, power
  - Smaller RPA's, less power, smaller solar arrays
    - Exciter output (20 mW) through an HGA could produce meaningful data rates at Mars -- 10s of kbps
  - Smaller, lower gain antennas, reduced antenna pointing requirements
  - Lower mass spacecraft could enabled missions using solar sails or other low impulse propulsion
  - Decrease the need for gravity assists, shortening interplanetary cruise and decreasing operations costs

SKA Applied to
Deep Space Communications

Continued

- Use SKA to support multiple spacecraft simultaneously
- Use SKA for *in situ* communications where comm/nav networks are unavailable
- Use small sub-arrays, “dial-up” needed aperture,
  - Near-Earth post-launch support
  - Interplanetary Cruise for navigation data acquisition with low rate telemetry
- Use SKA to support of spacecraft in distress

SKA Applied to Deep Space Navigation

- Use SKA to obtain real-time plane-of-sky spacecraft position simultaneously with Doppler and range
  - Provides valuable independent and complementary data to add to Doppler and range
    - ~50 nanoradian accuracy with 20 km array baselines, 10 minute integration
    - ~5 nanoradian accuracy with 500 km array baselines, 10 minute integration
    - Approach trajectories tend to be plane-of-sky
  - Large field-of-view expands spacecraft-spacecraft “delta DOR” and in some cases spacecraft-target opportunities
  - Near real-time access allows plane-of-sky measurement use in “terminal” navigation for landers and for spacecraft rendezvous

SKA Applied to Deep Space Navigation

Continued

- Uplinks with different frequencies from different sub-arrays could allow spacecraft autonomous plane-of-sky position determination

SKA Applied to
Entry, Descent, and Landing (EDL)

- Factor of 100 increase in sensitivity could allow meaningful data rates over low - medium gain antennas
- Combination of high resolution angle data with Doppler and range allows real-time monitoring of spacecraft location
- Tone communication with tumbling spacecraft

SKA Applied to Radio Science

- Radio Occultation
  - higher resolution ionospheric, atmospheric and ring profiles
  - detection of tenuous atmospheres (Pluto) and rings
  - Probe deeper into thick atmospheres
  - Horizontal “tomography” of atmospheres and rings using multiple beams
- Gravity fields and celestial mechanics
  - Combination of angle measurements with Doppler puts tighter constraints on spacecraft trajectory models and gravity fields
- Bi-static radar
  - near-backscatter bistatic studies of icy surfaces
- 3D *in-situ* plasma measurements with multiple spacecraft

SKA Applied to Planetary Radar

- New targets
  - Range and image all the known solid body planets, major satellites and rings in the Solar System
  - Target smaller asteroids, further away
    - Improve the ephemeredes of more Earth crossing asteroids
- Better radar images
  - Image the Saturnian satellites with the same SNR as current Martian images
- Interferometric radar measurements
  - More numerous baselines
- Detection of spacecraft to ~2,000,000 km

The SKA - Other NASA Benefits

- Graceful degradation, downtime for maintenance
- Potential site diversity
- Arrays are less susceptible to RF interference
- Use of SKA requires no new development of spacecraft communications hardware
- Develop mutually constructive partnerships with the Radio Astronomy community
- Acquire and maintain core capabilities in signal processing and telecommunications within TMOD, JPL, NASA.

The SKA as a Tool for Deep Space Communications, Navigation, and Science

Technical Challenges

- Phase-arraying thousands of signals
  - Need to find economical way to scale current signal combining architectures
- Uplink arrays
  - Need to develop prototype uplink array concepts
- Need to develop low cost, mass production of antennas and electronics
  - Terrestrial communications applications are leading the way
- Develop wideband, very low noise receivers and feeds
  - ATA has 0.5 to 11 GHz instantaneous bandwidth; would like 2 to 40 GHz for SKA.

SKA as an element of the DSN
Open Issues

- A Square Kilometer Array <u>will</u> eventually be built
  - Will NASA, JPL, DSMS help make it happen?
  - How will the NASA flight projects and other DSMS users use it? *How will you use it?*

SKA as an element of the DSN

Next Steps

- ⇒ Collect mission concepts and other applications for a major breakthrough in tracking station performance
- ⇒ Develop the case for NASA/JPL participation in the planning, development, and implementation of the SKA
- Secure NASA funding and agreements for DSN participation in the SKA consortium
- Procure prototype antennas and electronics
- Demonstrate ranging and uplink capabilities using arrays
- Develop more detailed array life cycle cost estimates

The SKA Applied to Landscape Design

Conclusions

- A large array of antennas is the **only** technology that promises orders of magnitude increase in sensitivity (G/T) at RF
- A large array like the SKA will be built based on its enormous potential for radio astronomy. NASA participation will:
  - make it happen sooner
  - allow deep space missions and other current users of the DSN to utilize the array's enormous potential
- In order to maintain its status as a preeminent provider of services to the space exploration community, the DSN must actively participate in the development and implementation of the SKA